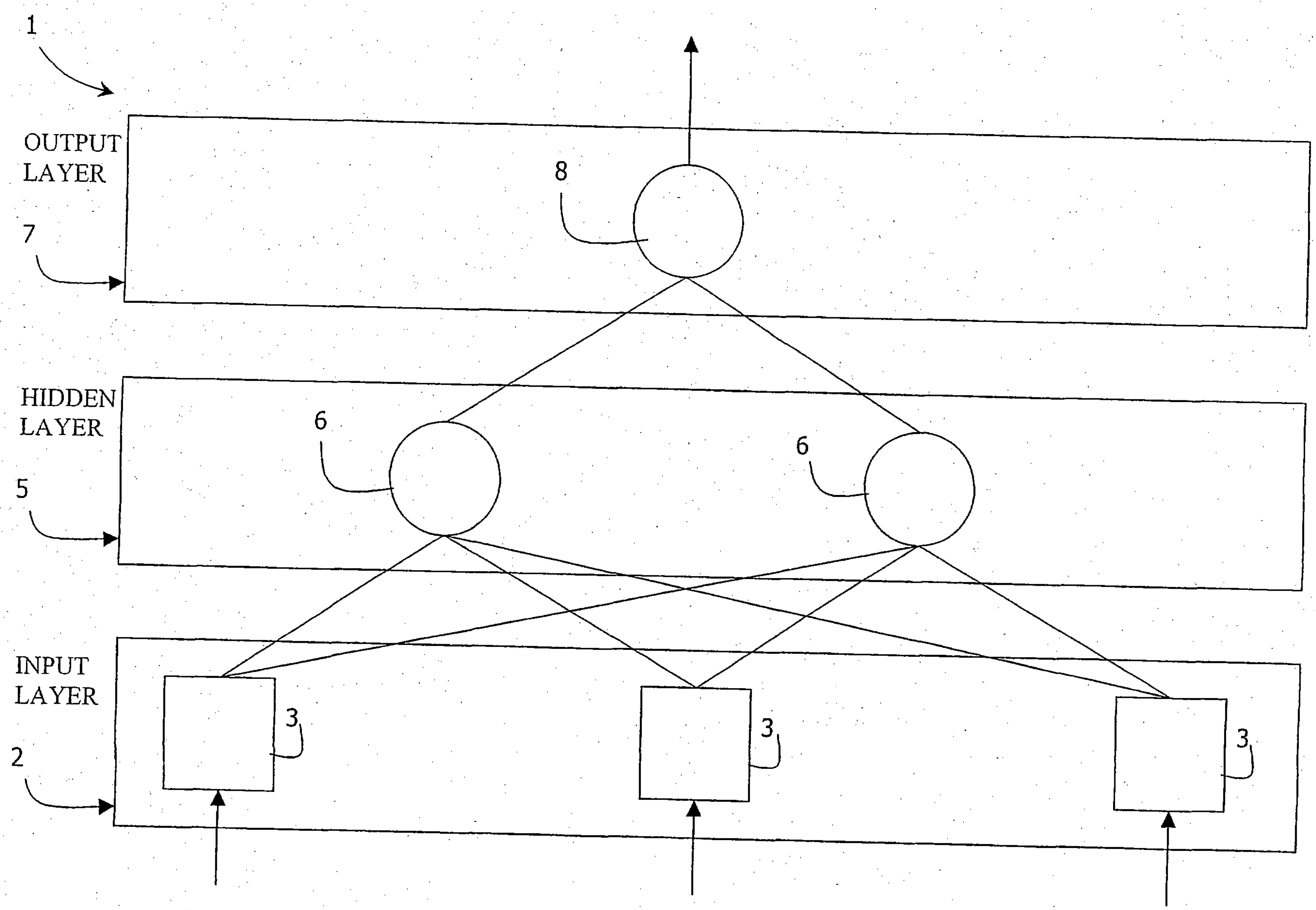


FIG. 1.

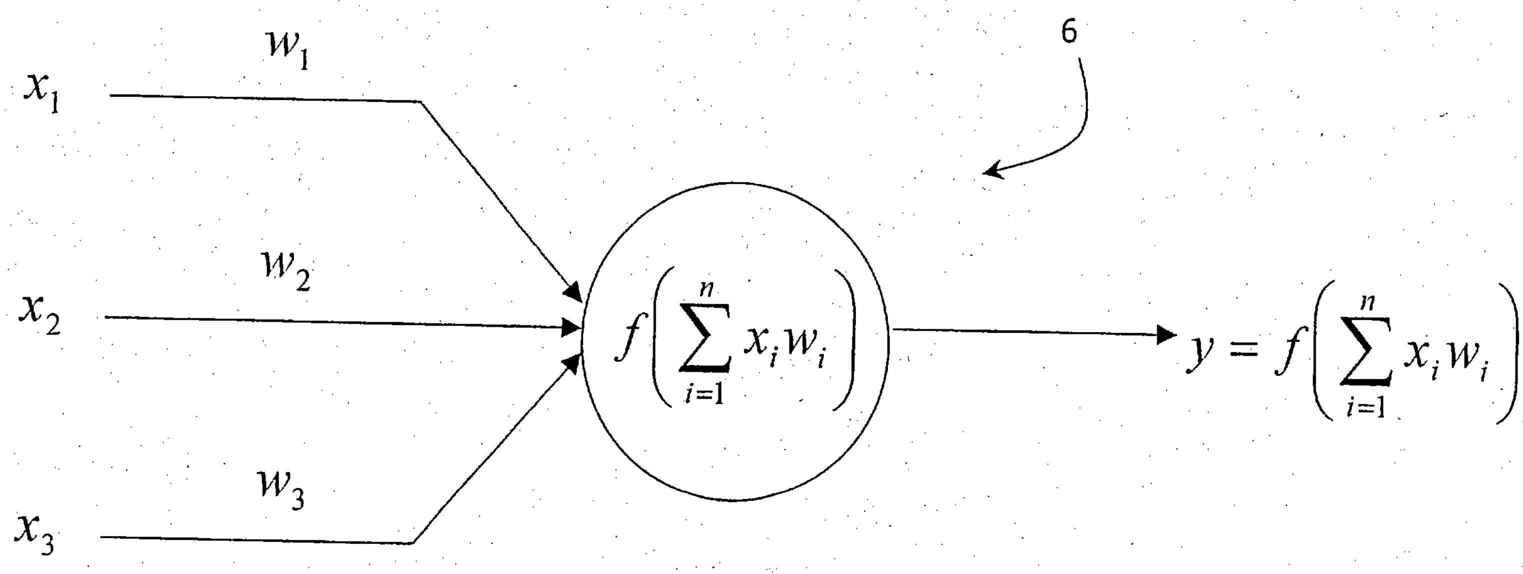
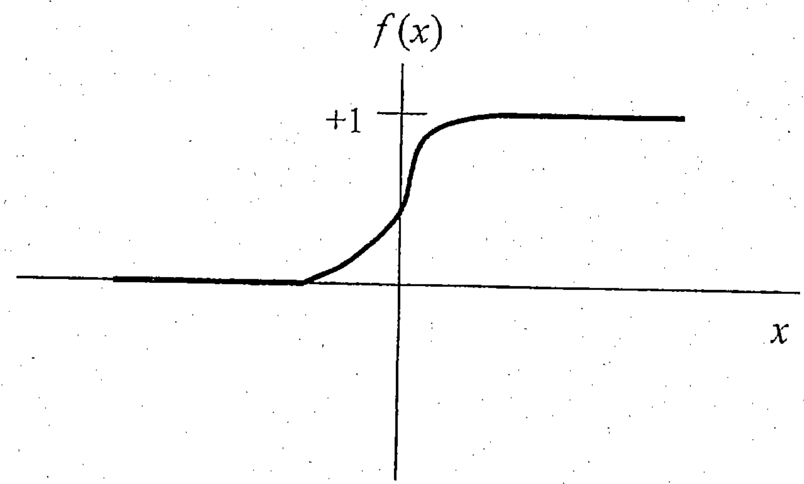


FIG. 2.



$$f(x) = \frac{1}{\left(1 + e^{-(x+T)}\right)}$$

FIG. 3.

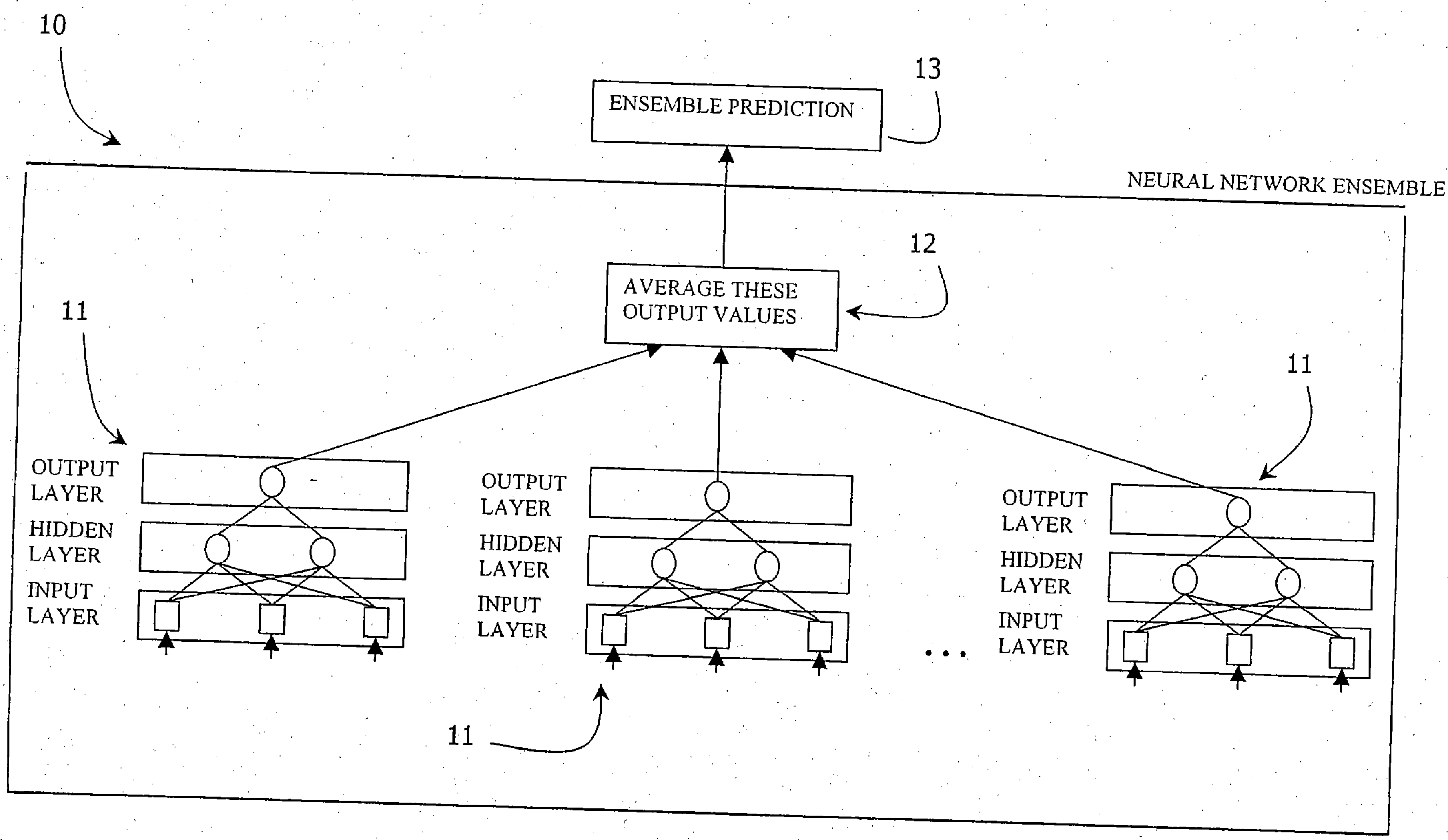

10
13
ENSEMBLE PREDICTION
NEURAL NETWORK ENSEMBLE
12
AVERAGE THESE
OUTPUT VALUES
11
OUTPUT
LAYER
HIDDEN
LAYER
INPUT
LAYER
11
11

FIG. 4.

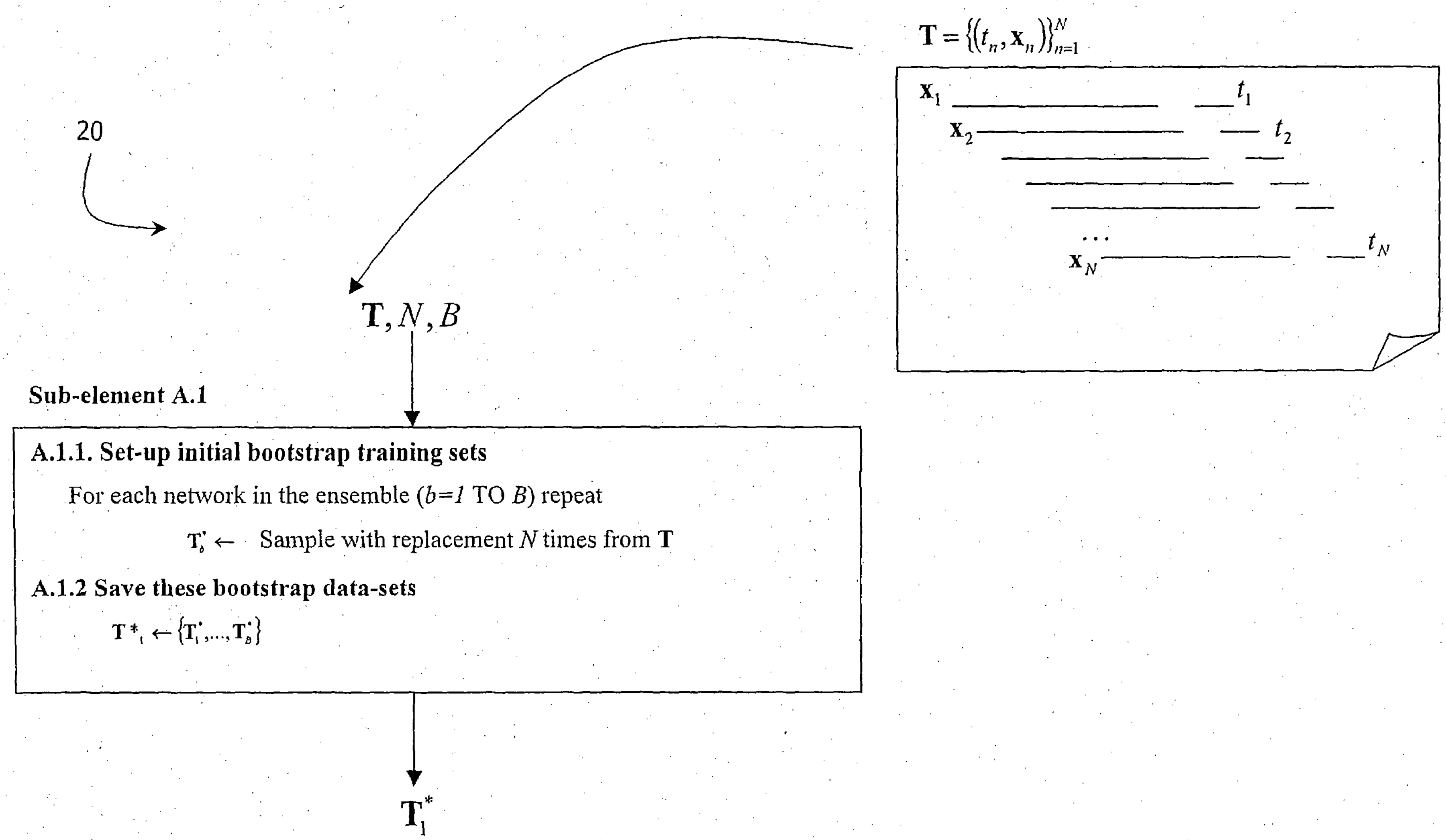

20
$\mathbf{T} = \{(t_n, \mathbf{x}_n)\}_{n=1}^{N}$
$\mathbf{x}_1$ t_1
$\mathbf{x}_2$ t_2
...
$\mathbf{x}_N$ t_N
$\mathbf{T}, N, B$
Sub-element A.1
A.1.1. Set-up initial bootstrap training sets
For each network in the ensemble (b=1 TO B) repeat
$\mathrm{T}_b^* \leftarrow$ Sample with replacement N times from $\mathbf{T}$
A.1.2 Save these bootstrap data-sets
$\mathbf{T}^*_1 \leftarrow \{\mathrm{T}_1^*, \ldots, \mathrm{T}_B^*\}$
$\mathbf{T}_1^*$

FIG. 5.

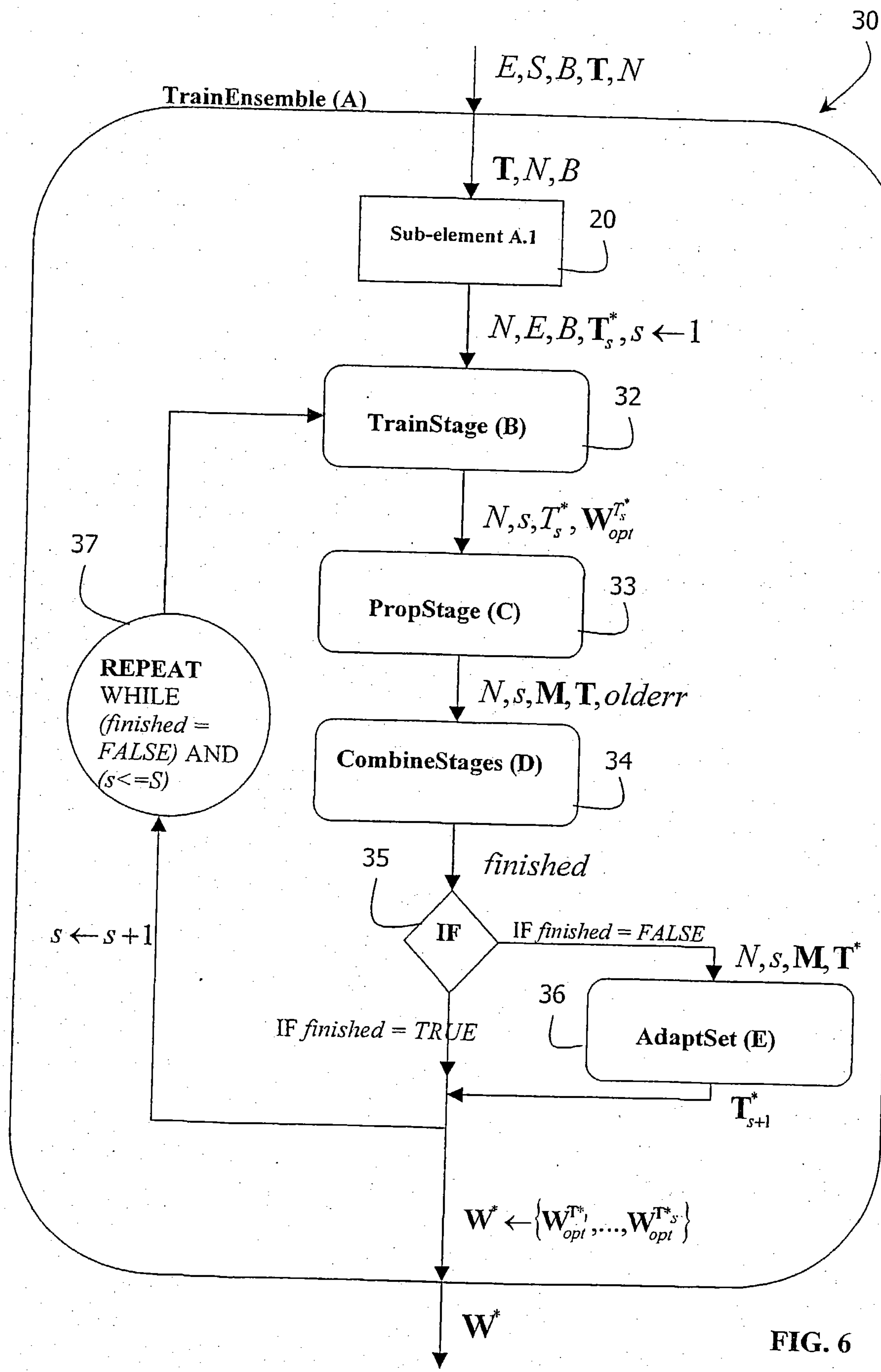

30
$E,S,B,\mathbf{T},N$
TrainEnsemble (A)
$\mathbf{T},N,B$
Sub-element A.1
20
$N,E,B,\mathbf{T}_s^*,s \leftarrow 1$
TrainStage (B)
32
$N,s,T_s^*,\mathbf{W}_{opt}^{T_s^*}$
PropStage (C)
33
37
REPEAT
WHILE
(finished = FALSE) AND (s<=S)
$N,s,\mathbf{M},\mathbf{T},olderr$
CombineStages (D)
34
finished
35
IF
IF finished = FALSE
$N,s,\mathbf{M},\mathbf{T}^*$
$s \leftarrow s+1$
36
AdaptSet (E)
IF finished = TRUE
$\mathbf{T}_{s+1}^*$
$\mathbf{W}^* \leftarrow \{\mathbf{W}_{opt}^{\mathbf{T}^*_1},\ldots,\mathbf{W}_{opt}^{\mathbf{T}^*_S}\}$
$\mathbf{W}^*$

FIG. 6

32

$N, E, S, B, \mathbf{T}_s^*$

TrainStage (B)

B.1 Copy training sets for this stage into individual sets

$\{\mathbf{T}_1^*,\ldots,\mathbf{T}_B^*\} \leftarrow \mathbf{T}_s^*$

B.2 Compute generalisation error estimates for each training vector

For every training vector (*n=1* TO *N)* in the original training set repeat

For every epoch (*e=1* TO *E*) repeat

Compute:

$$\mathbf{G}_e^n \leftarrow \left(t_n - \frac{\sum_{b=1}^{B} \gamma_n^b \left(\phi\left(\mathbf{x}_n ; \mathbf{w}_e^{\mathbf{T}_b^*} \right) \right)}{\sum_{b=1}^{B} \gamma_n^b} \right)^2$$

B.3 Aggregate the ensemble generalisation error estimates

For every epoch (*e=1* TO *E*) repeat

Compute:

$$\mathbf{A}_e \leftarrow \frac{1}{N} \sum_{n=1}^{N} \mathbf{G}_e^n$$

B.4 Find the best value for *e* for each network in the ensemble

$$e_{opt} \leftarrow \arg\min_e (\mathbf{A}_e)$$

$$\mathbf{W}_{opt}^{\mathbf{T}^*_s} \leftarrow \mathbf{w}_{e_{opt}}^{\mathbf{T}^*_s}$$

$\mathbf{W}_{opt}^{\mathbf{T}^*_s}$

FIG. 7

33

$N, s, \mathbf{T}_s^*, \mathbf{W}_{opt}^{\mathbf{T}_s^*}$

PropStage (C)

C.1 Compute ensemble outputs for each training example for this stage

For every training vector ($n=1$ TO N) in the original training set

Compute:

$$\mathbf{M}_n^s \leftarrow \frac{\sum_{b=1}^{B} \gamma_n^b (\phi(\mathbf{x}_n ; \mathbf{w}_{opt}^{\mathbf{T}_s^*}))}{\sum_{b=1}^{B} \gamma_n^b}$$

$\mathbf{M}$

FIG. 8

34

$N, s, \mathbf{M}, \mathbf{T}, olderr$

CombineStages (D)

D.1 Set new variable as upper bound on number of stages so far

$numstages \leftarrow s$

D.2 Sum ensemble outputs across stages

For every training vector (*n=1* TO *N*) in the original training set

Compute:

$$\mathbf{S}_n \leftarrow \sum_{j=1}^{numstages} \mathbf{M}_n^j$$

D.3 Calculate staged ensemble generalisation error

$$newerror \leftarrow \frac{1}{N} \sum_{n=1}^{N} (t_n - \mathbf{S}_n)^2$$

D.4 If no improvement finish training

IF $s=1$

$olderr \leftarrow newerror$

ELSE IF $(newerror > (\partial * olderr))$

$finished \leftarrow 1$

ELSE IF $(newerror < olderr)$

$olderr \leftarrow newerror$

$finished$

FIG. 9

36

AdaptSet (E)

$N, s, \mathbf{M}, \mathbf{T}_s^*$

E.1 Set new variable as upper bound on number of stages so far

numstages $\leftarrow s$

E.2 Sum ensemble outputs across stages

For every training vector ($n=1$ TO N) in the original training set

Compute:

$$\mathbf{S}_n \leftarrow \sum_{j=1}^{numstages} \mathbf{M}_n^j$$

E.3Adapt training set

For every training vector ($n=1$ TO N) in the original training set

Compute:

$$t_{n,s+1}^* \leftarrow t_{n,s}^* - \mathbf{S}_n$$

$\mathbf{T}_{s+1}^*$

FIG. 10